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Energy impact of ASHRAE's museum climate classes: a simulation study on four museums with different quality of envelopes

Rick Kramer^{a*}, Henk Schellen^a, Jos van Schijndel^a^a University of Technology Eindhoven, 5600 MB Eindhoven, The Netherlands

Abstract

ASHRAE's indoor climate design classes for general museums, galleries, archives and libraries are well known: AA (most strict), A, B, C and D (least strict). Museum staff often select class AA, presuming to gain the best overall preservation result that is possible. However, the exact consequences on the energy demand are unknown and therefore barely taken into account when selecting a class. This study quantifies the energy demand of four museum zones with different quality of envelopes (ranging from historical to state-of-the-art museum envelopes), conditioned according to ASHRAE's climate classes. The lower and upper limits of indoor temperature and relative humidity, and the resulting energy demand are determined using building simulations. The conclusions: (i) conditioning according to class B significantly saves energy compared to class A, while class B is still considered as precision control and protects most artefacts; (ii) moving down one class, e.g. from class AA to A, saves relatively more energy for a state-of-the-art building than for a historical building; (iii) Subclasses A_d (larger daily fluctuations) and A_s (seasonal adjustments, but smaller daily fluctuations) pose the same risk on the collection, but subclass A_d requires less humidification and dehumidification than A_s , so larger daily fluctuations may be preferred above seasonal adjustments.

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* Corresponding author. Tel.: +31402475613.

E-mail address: r.p.kramer@tue.nl

1. Introduction

Museums are dedicated to protect their artwork collection. Amongst other things, the indoor climate is of utmost importance. However, museum indoor climate conditioning evolved in the 20th century along with technology: not the collection, nor the building requirements, but the capability of the HVAC installations determined the level of conditioning [1]. In the late 1990's work began on a completely new ASHRAE Handbook chapter on museum climates [2] to combine knowledge from scientists and professionals. Now, ASHRAE's indoor climate classes for general museums, galleries, archives and libraries [3] are well known: AA, A, B, C and D, in which AA dictates the most strict indoor climate. The lead-author of the section on temperature (T) and relative humidity (RH) specifications was Stefan Michalski who included some new concepts [2]: (i) setpoints may vary from the standard; (ii) estimated risks are provided for each class; (iii) a wide range of options for seasonal adjustments for energy efficiency. Nevertheless, museum staff often select class AA, presuming to gain the best overall preservation result that is possible. However, common knowledge from experienced museum professionals shows that many collections survived in less strict conditions and that many museums that claimed to reach the ideal could not [2]. This is supported by measurements [4]. Moreover, the consequences on the energy demand are unknown and therefore barely taken into account when selecting a climate class.

This study quantifies the energy demand via computer simulations of four museum zones with different Quality of Envelope (QoE), conditioned according to the ASHRAE's climate classes. The four QoE's vary from an envelope typical for historical buildings (QoE 1) to an envelope typical for a state-of-the-art museum building (QoE 4). The hourly lower and upper limits of indoor T and RH are determined via building simulations. Then these setpoints are used in building simulations to obtain the required energy demand for achieving an indoor climate according to a specific ASHRAE indoor climate class.

2. Methodology

2.1. Building model

A museum zone model was developed using HAMBASE [5,6], a Heat Air and Moisture modeling and simulation tool developed in MATLAB at the University of Technology Eindhoven. The model was used to simulate indoor operative temperature T_{op} , RH and energy demand for heating, cooling and (de)humidification. In HAMBASE, an indoor zone model is coupled to an envelope model. The thermal indoor zone model consists of two coupled equations: the heat balance of the air temperature T_{air} , and the heat balance of the resultant temperature T_x (a combination of T_{air} and $T_{radiant}$). The hygric indoor model takes the moisture storage in the air and moisture storage in furniture into account. The heat and vapor flows into the walls are calculated by the envelope models that are connected to the indoor zone models. The thermal and hygric envelope models are second order models. Vapor transfer through a wall is negligible compared to the vapor transfer by ventilation, so only the latter is taken into account. The moisture storage capacity of the walls is temperature dependent. However, the temperature dependency of the moisture storage is linearized. Because of this linearization, the hygric envelope model is accurate between 20 % and 80 % RH, but inaccuracy might become significant towards 95 % RH, which didn't occur in this study. The contribution of radiation is distributed over the walls resulting in one area weighted average surface temperature.

Four museum zones have been modelled with dimensions as shown in Fig. 1. The south and west walls are external walls with windows of 5 m² each. The ceiling, floor, north and east walls are adiabatic.

The four zones' quality of envelope (QoE) varies as specified in Table 1: the exterior wall, glazing and infiltration rate vary from an envelope that is typical for a museum housed in a historical building (QoE 1) to a state-of-the-art envelope that is typical for a modern museum building (QoE 4). The HVAC systems were deliberately excluded in the simulations to obtain the energy demand. In this way, the energy performance of the different setpoint strategies is revealed, independently of the type of HVAC system. Internal heat sources included lighting (9 W/m²) and visitors (500 W). Internal moisture sources only included visitors (1e-5 kg/s). The sources are only active during opening hours from 10 am to 5 pm. For detailed model input, see [4].

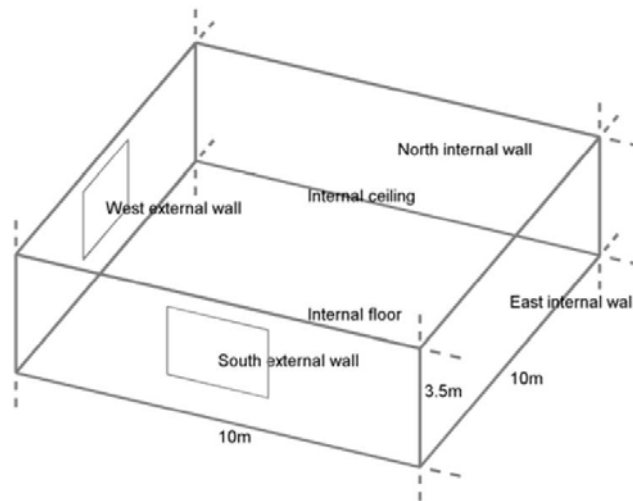


Fig. 1. Dimensions and orientations of the museum zone.

Table 1. Specification of the used Quality of Envelopes (QoE).

	QoE 1	QoE 2	QoE 3	QoE 4
Exterior wall	400 mm brick, plastered	400 mm brick, plastered	400 mm brick, 100 mm insulation, plastered	100 mm brick, cavity, 150 mm insulation, 100 mm brick, plastered
Glazing	Single	Double	Double low-e	Double low-e
U-value	5.7 W/m ² K	3.2 W/m ² K	1.4 W/m ² K	1.31 W/m ² K
Convection factor	0.010	0.030	0.030	0.047
Solar gain factor	0.80	0.70	0.65	0.31
Infiltration rate	1 h ⁻¹	0.4 h ⁻¹	0.2 h ⁻¹	0.1 h ⁻¹

2.2. Outdoor climate data

For the building simulations, outdoor climate data of the year 2003 were retrieved from the Royal Netherlands Meteorological Institute's database (location De Bilt). The data include hourly values for external dry bulb T, RH and global solar radiation, which is converted into direct and diffuse solar radiation. In the Netherlands, the year 2003 had a cold winter and a hot summer making it very suitable to discriminate between ASHRAE's climate classes.

2.3. Calculating setpoints according to ASHRAE's climate classes

The ASHRAE's indoor climate guidelines for museums, galleries, archives and libraries include limits for short-term (daily) and long-term (seasonal) fluctuations, and recommended levels for T and RH. These specifications are shown in table 3 in [3]: Four classes for T and RH are defined, accompanied by the resulting collection risk: AA (no risk to most objects), A (small risk to highly vulnerable objects, no risk to most objects), B (moderate risk to highly vulnerable objects, small risk to most objects), C (prevent high risk extremes), D (prevent dampness). Class A is divided into sub-class A_d, with larger daily fluctuations, but no seasonal adjustment and sub-class A_s, with seasonal changes but smaller daily fluctuations.

The four museum zones with varying QoE were simulated using setpoints for T and RH that are calculated according to ASHRAE's specifications. This process is shown in Fig. 2, in which the seasonal average is calculated using a period of three months according to,

$$X_{runningi} = \frac{1}{n} \sum_{a=i-n/2}^{i+n/2} X_a \quad (1)$$

where $X_{running}$ denotes the seasonal running average, n the number of data points in one season (averaging window), i the current data point in the data range, a the point in the seasonal period (averaging window).

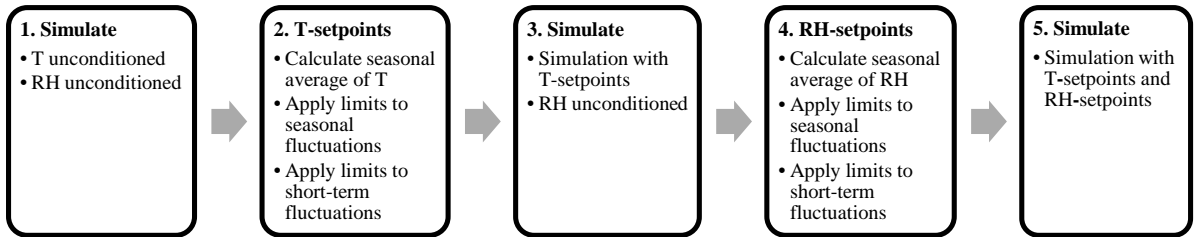


Fig. 1. Process of calculating setpoints for T and RH that correspond to climate classes.

3. Results and discussion

Four museum zones with varying quality of envelope were simulated using T and RH setpoints according to ASHRAE's museum indoor climate classes (AA, A_s, A_d, B, C, D). Fig. 3 shows the resulting indoor climates of QoE 3. The red lines represent the setpoints for heating and cooling (T), and humidification and dehumidification (RH).

Class AA clearly shows the limitation of seasonal fluctuations. Furthermore, class AA allows no seasonal adjustment of RH, but allows a bandwidth of 10% RH. Class A_s allows more seasonal adjustment of T and RH. Class A_d allows no seasonal adjustment of RH, but larger daily fluctuations (20% RH). Class B allows more daily fluctuations of T and RH, also seasonal adjustments of RH. Class C poses only lower and upper limits to RH and class D poses only an upper limit to RH.

The required energy for heating, cooling and (de)humidification is shown in Fig. 4. Note that the scales of the y-axes are not the same: the energy impact of the QoE is clear as improving the building envelope results in significant energy savings.

The results also show that an appropriate climate class should be chosen with care: the energy impact and resulting energy bill are highly influenced by the climate class. Classes C and D are rarely applicable to museums. Climate class B is regarded as the appropriate class for museums housed in historical buildings: the limited need for humidification prevents damage due to condensation. The results show that class B significantly saves energy compared to class A.

Subclasses A_d and A_s pose the same risk on the collection, but the results show that subclass A_d requires less humidification and dehumidification than A_s. Moreover, subclass A is easier to implement in a control strategy than subclass A_s, because it simply implies a setpoint with bandwidth of 20% RH without seasonal changes. Therefore subclass A_d may be preferred.

Another result seems counter intuitive: moving down one class, e.g. from class AA to A_s, saves relatively more energy in QoE 4 (state-of-the-art) than in QoE 1 (historical), but absolute savings are larger in QoE 1. It was already known that less strict indoor climates pose less risk to historical envelopes, and that energy will be saved, but the results show that the energy saving effect is also significant for museums with state-of-the-art envelopes.

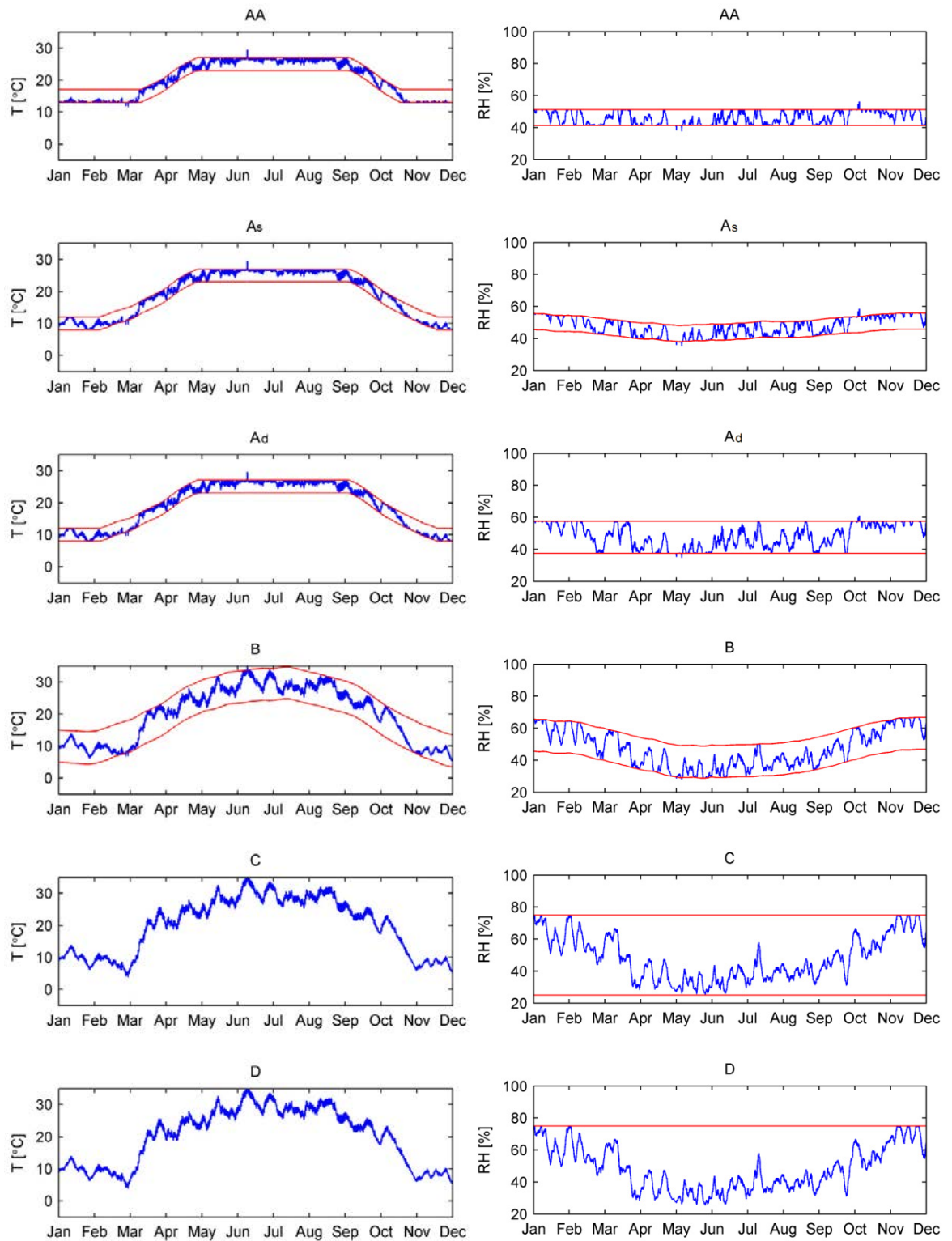


Fig. 3. Resulting indoor T (left) and RH (right) for QoE 3, conditioned according to ASHRAE's museum indoor climate classes.

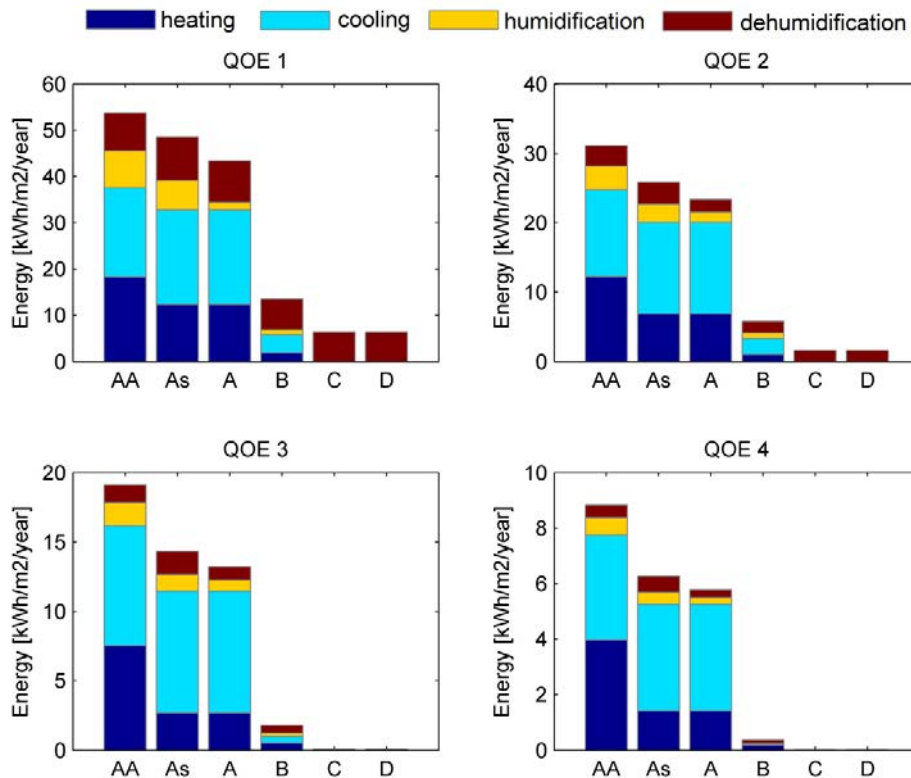


Fig. 2. Specification of energy demand per QoE.

4. Conclusions

- Class B significantly saves energy compared to class A, while class B is still considered as precision control and, probably, adequately protects most artefacts (highly vulnerable artefacts may be placed into display cases).
- Moving down one class, e.g. from AA to A, saves relatively more energy in QoE 4 (modern) than in QoE 1 (historical). So, also in modern buildings it is highly relevant to study collection needs and not to condition unnecessarily strict.
- Subclasses A_d and A_s pose the same risk on the collection, but subclass A_d requires less humidification and dehumidification than A_s, so larger daily fluctuations are preferred above seasonal adjustments.
- Thermal comfort was not included, so the results' trends are valid, but absolute energy demands will differ. The effect of comfort requirements needs further research.

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